Two Hemispheres—One Brain:
Functions of the Corpus Callosum, pages 3–20
Published 1986 by Alan R. Liss, Inc.

1986 ✓ (252)

Consciousness, Personal Identity, and the Divided Brain

ROGER SPERRY
Division of Biology, California Institute of Technology, Pasadena, California 91125

I

It has now become a familiar story in neuroscience that when you divide the brain surgically by midline section of the cerebral commissures the mind also is correspondingly divided. Each of the disconnected hemispheres continues to function at a high level, but most conscious experience generated within one hemisphere becomes inaccessible to the conscious awareness of the other. The parallel mental functions of the separated hemispheres are found to differ further in important ways, the most conspicuous being that the disconnected left hemisphere retains the ability to speak its mind, much as before, whereas the right hemisphere, for most practical purposes, is unable to express itself either in speech or in writing.

In turning to examine more closely these and related phenomena, as they bear on our present topic, I shall be drawing on studies by a long line of associates and myself conducted on a select group of about a dozen so-called commissurotomy or split-brain patients of Drs. Philip Vogel and Joseph Bogen, neurosurgeons at the White Memorial Medical Center in Los Angeles. This commissurotomy operation is performed in rare cases as a last resort measure to help control severe intractable epilepsy.

A few points about the surgery need to be kept in mind: First, it permanently divides in the brain nearly all direct connections mediating cross-talk between the left and right hemispheres (see Fig. 1). This includes those fiber systems that normally interconnect left and right halves of the cortical

Public lecture presented at the Smithsonian Institution, December 1977 in the Frank Nelson Doubleday Lecture Series on "The Human Mind." Published in the Hecaen memorial issue of *Neuropsychologia*, Vol. 22. It is presented here with minor editorial revision and updating.

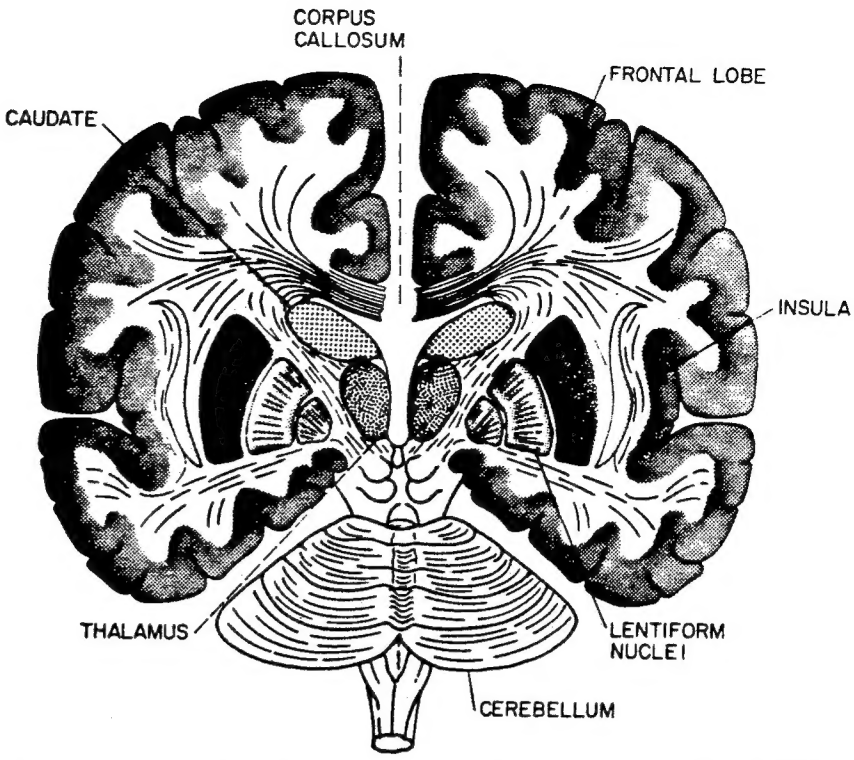

Fig. 1. Nature of hemispheric separation effected by surgical section of forebrain commissures. Some indirect cross communication remains possible through intact midbrain and associated brainstem structures.

field for vision. As a result the visual perception of objects in each hemisphere becomes restricted to half the normal field of view, cut off sharply at the vertical midline and center of gaze. The left hemisphere sees things in the right half of the visual field, using either one or both eyes, while things to the left are perceived by the right hemisphere. Interconnections are severed also between the cerebral representations for the right and left hands and feet, including both the primary sensory projections and also the main motor controls for skilled movement. Hence things felt with the right hand are perceived mainly in the left hemisphere, which also governs related motor adjustments of the same hand. Conversely, motor coordination and tactual perception for the left hand are mediated predominantly by the right hemisphere. In addition, the surgery cuts off the functions of

the right hemisphere from speech and the main language centers located (in approximately 95% of the population) in the left hemisphere (see Fig. 2).

A leading question with which we shall be concerned can be stated as follows. Are there really in the brain thus divided, two separately conscious minds, in effect two co-conscious selves sharing the one cranium? And, if so, what does this signify regarding the nature and the substrate of mind and the unity of the conscious self in the normal intact brain?

The first point to be emphasized is that these patients following surgery appear in ordinary, everyday behavior to be very typical, single-minded, normally unified individuals. What prompted our studies in the beginning was a series of published reports supporting the conclusion that no definite symptoms are detected after surgery, even with extensive neurological and psychological testing. (For a review of the earlier literature, see [3].) Usually a year or so is required to recover fully from the extensive neural trauma caused by section of the cerebral commissures, which include the largest fiber systems of the brain, estimated to contain well over 200 million nerve fibers. After recovery patients without other brain damage are able to return to school or to household duties, or to an undemanding job assignment. Two years after surgery, a typical commissurotomy patient without complicating disorders could easily go through a complete routine medical examination without revealing to an uninformed practitioner that anything is abnormal. Nor is there any marked change in the verbal scores on the standard IQ test. Complaints about short-term memory are common especially in the early years after surgery. However, the general behavior and conversation during the course of a casual social encounter without special tests typically reveals nothing to suggest that these people are not essentially the same persons that they were before the surgery with the same inner selves and personalities.

Despite the outward seeming normality, however, and the apparent unity and coherence of the behavior and personality of these individuals, controlled lateralized testing for the function of each hemisphere independently (see Fig. 3) indicates that in reality these people live with two largely separate left and right domains of inner conscious awareness. (The basic "split-brain" syndrome in man is reviewed in [28] and [33]; the split-brain animal work is reviewed in [24] and [26].) Each hemisphere can be shown to experience its own private sensations, percepts, thoughts, and memories, which are inaccessible to awareness in the other hemisphere. Introspective verbal accounts from the vocal left hemisphere show a striking lack of awareness in this hemisphere for mental functions that have just been performed immediately before in the right hemisphere. In this respect each surgically disconnected hemisphere appears to have a mind of its own, each capable of controlling the behavior of the body but each cut off from, and oblivious of, conscious events in the partner hemisphere.

Following the surgery these people are unable to recognize by sight something they have just looked at in one visual half-field if it is then

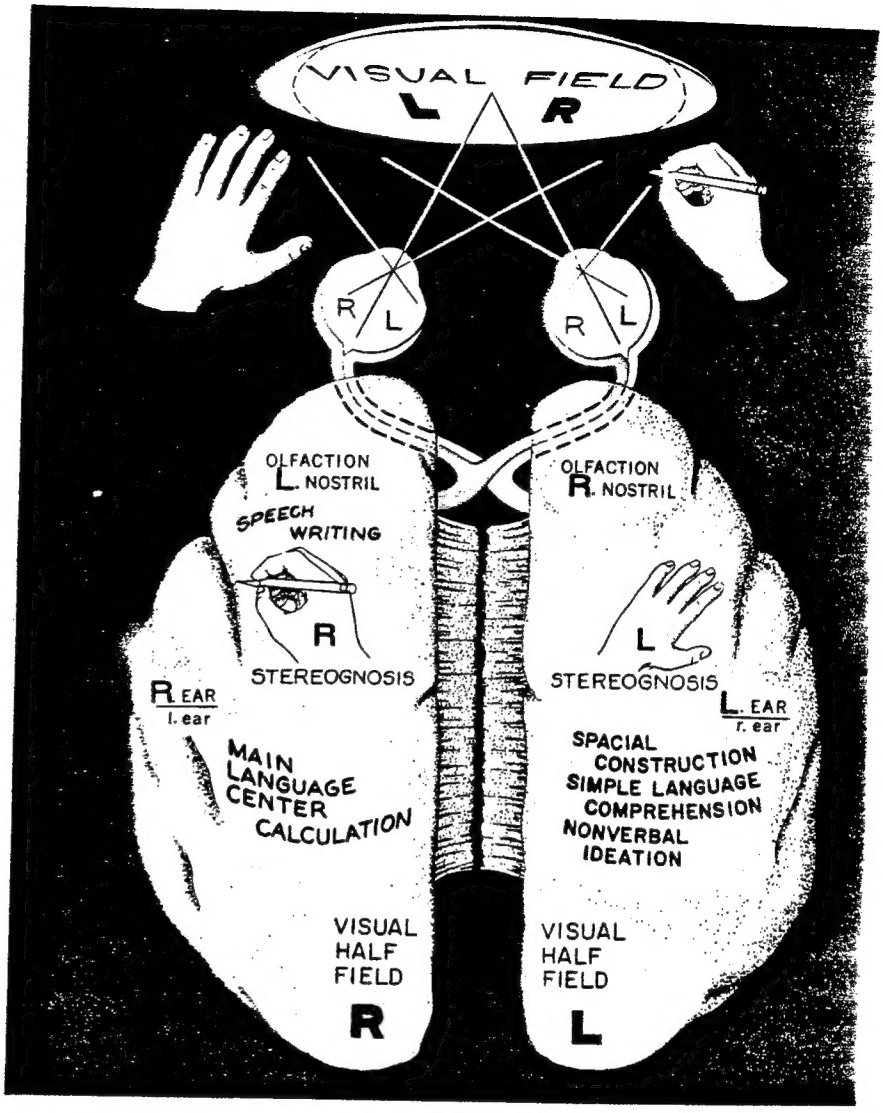

Fig. 2. Schematic representation of some of the main cerebral functions found to be lateralized following hemisphere disconnection.

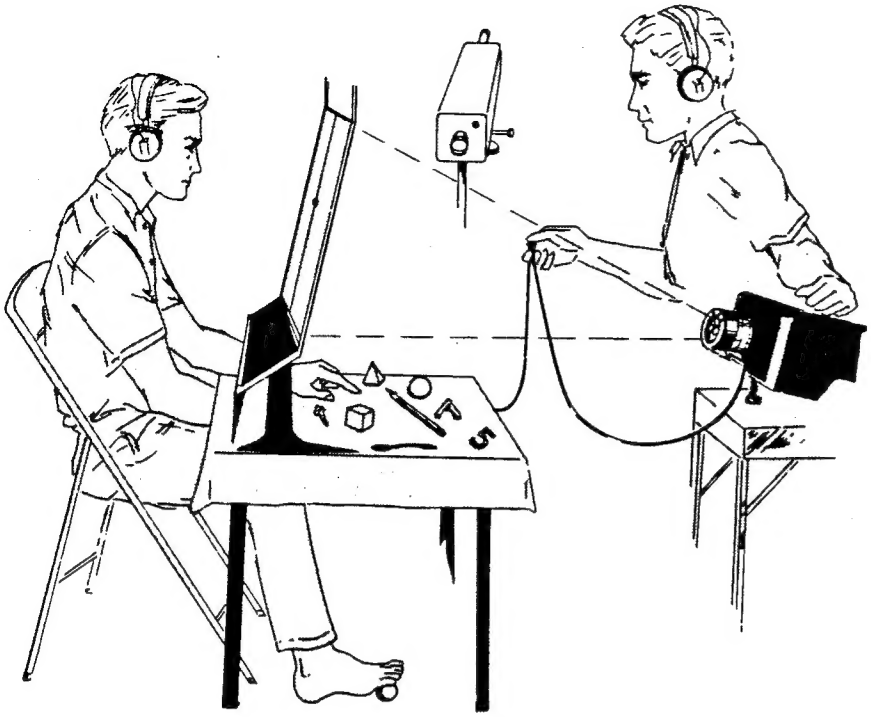

Fig. 3. Testing setup for determining laterality of mental functions in the surgically separated hemispheres.

presented across the vertical meridian in the opposite half-field of view. Objects perceived and identified tactually with one hand out of sight cannot be recognized with the other hand. Such objects also can be recognized in the corresponding half-field of vision but not in the opposite half-field. Similarly, odors identified through one nostril are not recognized through the other. Split-brain subjects fail to identify by verbal report objects felt with the left hand, seen in the left visual field, or smelled through the right nostril—in other words, things experienced within the right hemisphere. In the meantime, good perception and comprehension of these same test stimuli, of which the subject *verbally* disclaims any knowledge, is readily demonstrated *manually*, for example, by selective retrieval with the left hand, or by pointing to the correct picture in a choice array, or by appropriate hand signals or gestures (see Fig. 4).

From the collective results of these and similar kinds of tests, it is inferred that both disconnected hemispheres retain mental function at a

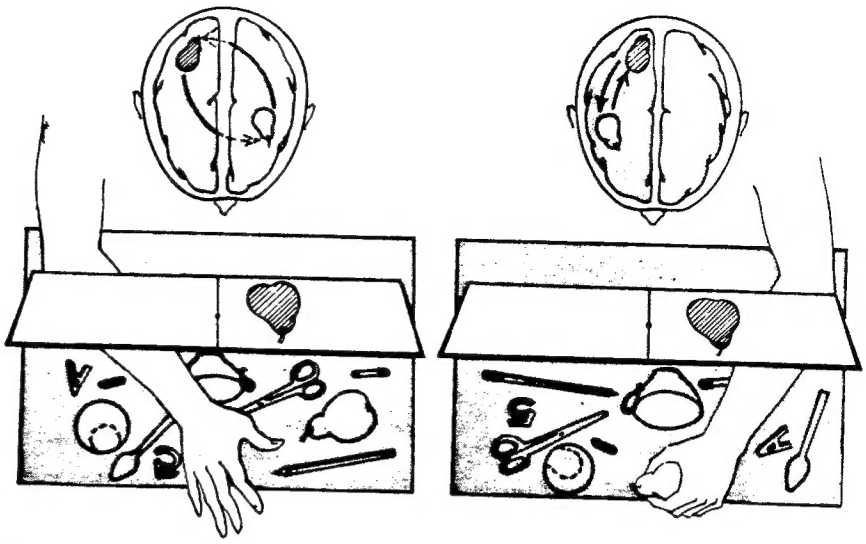

Fig. 4. Visual-tactual associations function correctly within either hemisphere but fail when cross left-right or right-left combinations are involved. Shown an object in left visual field, commissurotomy subjects report verbally that they "did not see" the left field stimulus (projected to right hemisphere). However, the subject then has no difficulty in finding the same stimulus object using the left but not the right hand. In this same setup, objects presented to the left hand for tactual identification cannot then be found with the right hand.

rather high level but are no longer cognizant of most mental functions of the partner hemisphere. The two disconnected hemispheres can further be shown to function concurrently but independently in parallel, by presenting different stimulus items simultaneously to the two hands or to the two visual half-fields. Under these conditions each of the two hemispheres are found to process concurrently their own separate perceptual-cognitive-mnemonic functions, and these may be grossly incompatible or even mutually contradictory [7] without either hemisphere's noticing that anything is wrong—so separate are the inner experiences of the disconnected hemispheres. The basic hemisphere disconnection syndrome is apparent as well in experiments with animals, as shown earlier in extensive studies on cats and sub-human primates during the 1950s [16,24,26,35]. As in man, the surgically separated hemispheres were found to perceive, learn, and remember independently at a high level, apparently with about equal proficiency on left and right sides.

Some authorities, concerned for the essential unity of the conscious self, have been reluctant to accept the conclusion that the mind is divided by

commissurotomy, maintaining instead that the mind and self remain unified within the language hemisphere or centered in the intact brain stem or in the person as a whole and that the nonspeaking, subordinate hemisphere operates only as a computer-like, unconscious automaton. (A recent treatment of this controversy may be found in Zangwill [39]; see also [17].) While these alternative interpretations may better conform with common concepts and traditions regarding the usual unity of the inner being, we have not been able to see any real justification in our test findings for denying consciousness to the disconnected mute hemisphere. Everything we have observed in many kinds of task performances over many years of testing reinforces the conclusion that the mute hemisphere has an inner experience of much the same order as that of the speaking hemisphere though differing in quality and cognitive faculties as will be outlined later. Clearly the right hemisphere perceives, thinks, learns, and remembers, all at a very human level. It also reasons nonverbally, makes studied cognitive decisions, and carries out novel volitional actions. Further, it can be shown to generate typical human emotional responses when confronted with affect-laden stimuli and situations.

II

Contrary to prior neurological doctrine based on unilateral lesions, the disconnected mute hemisphere has been found to be neither "word-blind" nor "word-deaf." To our initial surprise the comprehension of spoken instructions proved to be quite good in the right hemisphere, and the reading of printed words was performed moderately well. This comprehension in the minor hemisphere of spoken and written words was demonstrated by selective retrieval or pointing to corresponding objects or pictures. It was possible to go in the reverse direction also, i.e., from objects or pictures to words, written or spoken, and to go from spoken to written words and vice versa [10,28,32,33]. The right hemisphere could also spell simple three- and four-letter words with cut-out letters and read such words presented tactually, in contrast to the strong earlier impressions in neurology that the right hemisphere ordinarily is lacking in this kind of language comprehension and higher cognition.

Our findings are in line with the earlier controversial views of Hughlings Jackson but contradict many other observations that unilateral lesions confined to the left hemisphere alone may cause total global aphasia or leave a person word-deaf and/or word-blind despite the retention of an intact, undamaged right hemisphere. Although this disparity is still not fully resolved, the evidence seems to be settling out in favor of the conclusions drawn from commissurotomy. In particular, the language profile of the right hemisphere after commissure section conforms rather well to that

seen after rare surgical removals of the speech hemisphere for malignancy [21]. The vocabulary in the disconnected right hemisphere for comprehension of single spoken words about 10 years after surgery is found to have a mental age rating only slightly below that of the language hemisphere [38].

Earlier interpretations based on the symptoms produced by focal lesions that pictured the minor or subordinte hemisphere as a comparative retardate in brain evolution have had to be revised. The mental performance of this hemisphere after commissurotomy has been found repeatedly to be superior and dominant to that of the speaking hemisphere in a growing series of nonverbal, largely spatial tests. The tasks involved are of the kind where a single spatial image processed as a whole proves to be more effective than a detailed verbal or mathematical description. Examples include the copying of designs, reading faces, fitting forms into molds, discrimination and recall of nondescript tactual and visual forms, spatial transformations and transpositions, judging whole circle size from a small arc, grouping series of different-sized and -shaped blocks into categories, perceiving whole plane forms from a collection of parts, and intuitive apprehension of geometrical properties (this literature is still scattered, but see reviews in [24,26,28,33]; also see [8]).

Commissurotomy makes possible precise left-right comparisons for positive performance within the same brain, where most of the usual confusing background variables cancel out. Also the deceptive interhemispheric interference effects that complicate inferences drawn from focal lesions are eliminated or greatly reduced. Earlier doubts regarding the presence of advanced mental function in the minor hemisphere are now largely dispelled, and the concept of a complementary evolution of both hemispheres has come to replace our older classic view of a single one-sided dominance.

In any case, after watching repeatedly the superior performance of the right hemisphere in tests like the above, one finds it most difficult to think of this half of the brain as being only an automaton lacking in conscious awareness. Especially it is difficult to deny consciousness to the right hemisphere when it proves to be superior in novel tasks that involve logical reasoning and also when it generates typical facial expressions of satisfaction at tasks well done or of annoyance at its own errors or at those made by its uninformed partner hemisphere. Also difficult to reconcile with the concept of an automaton state is the clear ability of the right hemisphere to learn from experience, remembering test items it has seen or felt on prior testing sessions days or even weeks previously.

III

In many kinds of tests it is found that both disconnected hemispheres, regardless of differential speed and proficiency, are able to come up with the

correct answers. Further analysis indicates that the answers are arrived at, however, by different processing strategies or modes of thinking on left and right sides. Beyond the more obvious differences like those of speech, writing, and constructive visuospatial manipulation, more subtle organizational differences are indicated that tend to be obscured by individual patient variation in ordinary brain lesion studies, where it is taken for granted that some individuals will be more talkative than others, or more inclined to use verbal logic or visual imagery, etc. Under the conditions of commissurotomy, however, with the same subjects working the same test task with each hemisphere, even slight cognitive differences on left and right sides become meaningful. The same person is observed to employ consistently one or the other of two different kinds of mental strategy much like two different people, depending on whether the right or the left hemisphere is in use. The first evidence for this was obtained by Levy in 1969 [11] and has been repeatedly confirmed many times since. The discovery of complementary cognitive mode asymmetries following commissurotomy has prompted many further studies in normal, in brain-damaged, and in other select populations helping to better pinpoint and delineate the left-right cognitive differences and their variations.

Correlations of cerebral laterality have been extended to handedness, sex, occupational preferences and ability, special innate talents, eye dominance, genetic variations like Turner's syndrome, endocrinology, congenital dyslexia, autism, dreaming, hypnosis, inverted writing—and so on (an introduction and references to this large and rapidly expanding literature can be found in [12]). This has become a rapidly developing and fascinating story in itself of which I mention briefly a few summary points in passing. One important outcome is the increased insight and appreciation, in education and elsewhere, for the importance of nonverbal forms and components of learning, intellect, and communication. By the early seventies it already had become evident, from the standpoint of brain research, that our educational system and modern urban society generally, with its heavy emphasis on linguistic communication and early training in the three Rs, tends increasingly to discriminate against the nonverbal, nonmathematical half of the brain, which has its own perceptual-mechanical-spatial mode of apprehension and reasoning [27,29]. The amount of formal training given to right-hemisphere functions in our public schools traditionally has been almost negligible compared to that devoted to the specialities of the left hemisphere. The need now for better methods by which to detect, measure, and develop the nonverbal components of intellect before their critical development periods have passed is becoming widely recognized.

These and related developments also help bring an increased respect and regard for the inherent individuality in the structure of human intellect. People can no longer be assumed to be qualitatively similar at birth with equal potentiality for becoming a Beethoven or a Shakespeare, an Edison

or a Michaelangelo, etc. Different mental disciplines employ qualitatively different forms of cognitive processing that require different patterns of neural circuitry, the basic cerebral requirements for which are largely prewired. Even the potentialities of the two hemispheres of the same brain with respect to verbal and spatial functions are already at birth found to be qualitatively different [4,13,36]. There is strong indication that cognitive spatial ability is partly genetic and correlated with a sex-linked recessive. Evidence is mounting for other genetic and innate developmental variations involved in congenital dyslexia, autism, Turner's syndrome, androgenic females, and the like. Statistically the hemispheres mature earlier and show less lateralization in females, which is thought to account in part for the significant sex differences obtained in large-scale tests for intellectual factors and special abilities, females scoring higher in verbal tests and males in mathematics and tests that demand spatial processing. But many other variables are involved [12].

Actually, the more we learn, the more complex becomes the picture for predictions regarding any one individual, and the more it seems to reinforce the conclusion that the kind of unique individuality we each carry around in our inherent brain wiring makes that of fingerprints or facial features appear gross and simple by comparison. The need for educational tests and policy measures selectively to identify, accommodate, and serve the differentially specialized forms of intellectual potential becomes increasingly evident.

One must caution in this connection that the experimentally observed polarity in right-left cognitive style is an idea in general with which it is very easy to run wild. You can read today that things such as intuition, the seat of the subconscious, creativity, parapsychic sensitivity, the mind of the Orient, ethnocultural disposition, hypnotic susceptibility, the roots of counter-culture, altered states of consciousness—and what not—all reside predominantly in the right hemisphere. The extent to which extrapolations of this kind may eventually prove to be more fact or fancy will require many years to determine. In the meantime it is important to remember that the two hemispheres in the normal intact brain tend regularly to function closely together as a unit and that different states of mind are apt to involve different hierarchical and organizational levels or front-back and other differentiations as well as differences in laterality.

IV

In light of the mounting evidence for higher cognitive faculties and a complementary specialization in the right hemisphere, earlier claims that this hemisphere is not conscious have given way to intermediate positions. One of the latest concedes that the mute hemisphere may be conscious at

some levels, but denies that the non-language hemisphere possesses the higher, reflective, and self-conscious type of awareness that characterizes the human mind and is needed, so it is said, to qualify a conscious system as a "person" [5,19]. Self-consciousness is said to be predominantly a human attribute according to present thinking based on evidence drawn mainly from mirror tests for self-recognition [9]. In these terms, self-awareness seems to be largely lacking in animals below the primates and appears only to a limited extent in the great apes. In human childhood, self-consciousness is reported to emerge relatively late, somewhere around 18 months of age. Thus, self-consciousness, by developmental as well as by evolutionary criteria, is rated as a relatively advanced phase of conscious awareness.

We accordingly devised some tasks specifically designed to test for self-consciousness and levels of social awareness in the disconnected minor hemisphere. Procedures were used in which the subject, working with the mute hemisphere, merely has to point manually, on request, to select items in a choice array in order to indicate recognition, identification, personal approval, dislike—or whatever, as requested. The test arrays consist of four to nine pictures, drawings or photographs among which key personal and affect-laden items are inserted irregularly among neutral unknowns. The subject's vision is lateralized throughout to one hemisphere [37] and audio and visual tape recordings are used to analyze the more subtle aspects of responses.

Under these conditions, we found [34] that the right hemisphere can readily recognize and identify, with appropriate emotional reactions and social evaluations, pictures of the subject's self; his or her family, relatives, acquaintances, pets, and other belongings, familiar scenes, and also political, historical, and religious figures and television and screen personalities. The general level of recognition and quality of reaction were quite comparable throughout to those obtained from the same subject using the left hemisphere or free vision. All results to date support the conclusion that the right hemisphere, despite its language deficits, harbors a well-developed, seemingly normal conscious self with a basic personality and social self-awareness that is in close accord with the presurgical character of the patient and also with that of the speaking hemisphere of the same subject. Similar procedures were used to test for a sense of time and concern for the future in the right hemisphere, thus far with no evidence of abnormal deficit. The nonvocal hemisphere appears to be aware of daily and weekly schedules, important dates of the year, holidays, etc., and to make appropriate discriminations with regard to possible future accidents and family losses, life, fire, and theft insurance, and the like.

V

Accepting the dual conscious state of the hemispheres following surgical separation, students of the problem of personal identity and the nature of the conscious self have used the split-brain findings, along with cases of fugue states or multiple personality, to support the argument that it is no longer correct to think of a "person" as being correlated one-to-one with a body, that we need now to sharpen and refine the concept in terms of the critical brain states and neural systems involved. Such refinement becomes important in medicolegal decisions dealing, for example, with prolonged states of coma, stages in fetal development, vital organ transplants and so on.

An extreme position in regard to selfhood and "personal identity" is held by Puccetti [20] and Bogen [2] and others who infer that each hemisphere must have a separate mind of its own, not only after brain bisection but also in the normal intact brain as well. The surgery, they argue, simply reveals what already is there—namely, that we are all of us actually a dual compound of right and left minds, or "persons," as Puccetti puts it— and that this bicameral condition normally goes undetected because the experiences of right and left hemispheres are kept in close synchrony when the commissures are intact. I myself have favored the view that the conscious mind is normally single and unified, mediated by brain activity that spans and involves both hemispheres. This assumes, first, that the fiber systems of the brain mediate conscious awareness as do the switching mechanisms, synaptic interfaces, and other properties of the gray matter; and second, that fiber cross-connections between the hemispheres are not different in this respect from fiber systems within each hemisphere. The bilateral process can be viewed as an integrated mental emergent that, functionally and causally, is qualitatively different from, and more than, the mere sum of the left and right activities and further exerts downward causal control of the neuronal events in both hemispheres. In this view the two hemispheres function together as a closely integrated whole, not as a double, divided, or bicameral system. The two hemispheres, on these terms, normally perceive, think, emote, learn, and remember as a unit. They even speak as a unit in that the right hemisphere during speech is not idling or diverted but is actively focused to aid and sustain the cerebral processing involved in speech, to add tone and expression and to inhibit unrelated activity.

Even in the bisected brain, the question of whether there exists a right/left division of conscious experience is not subject to an unqualified "yes" or "no" answer. While the right/left division of many perceptual, cognitive, and mnemonic processes is clearly evident in lateralized testing, as already described, there are other aspects of consciousness that are not similarly divided. Two principle ways have been recognized in which the conscious

mind remains undivided after commissurotomy [28]. The first is attributed to the presence in the brain of bilateral wiring systems that ensure the representation of both left and right components of experience within each hemisphere. The cutaneous sensory system for the face is an example. Sensations from both left and right sides of the face mediated by the trigeminal nerves are each represented in both hemispheres. The kind of separation that applies for right and left halves of the field of vision and for right and left hands does not therefore hold with respect to the face. The same is true for audition and other systems like those mediating crude pain, temperature, pressure, and position sense, especially from the more axial parts of the body. Bilateral motor controls also are extensively present in both hemispheres. For lateralized testing we must necessarily be highly selective and take considerable pains to avoid activity that cannot be reliably confined to a single hemisphere. We thus depend heavily on moderately sophisticated input from the hands and from the half-fields of vision.

Bilateral representation within each hemisphere is further achieved by factors of a more functional kind. Exploratory movements of the eyes, for example, can provide bilateral representation of a perceived scene or object in both disconnected hemispheres. Similarly, exploratory movements of the hands with interchange and overlap can provide for a bilateral unified percept of an object in both hemispheres. These kinds of factors must be routinely guarded against and excluded in our lateralized testing.

Another fundamental way in which the conscious mind is not divided by commissurotomy is illustrated in the tests for self and social awareness mentioned above in which mental-emotional ambience or semantic surround generated in one hemisphere promptly spreads also to the second hemisphere. These "deep structure" components in conscious awareness, which appear to include attitudinal, orientational, emotional, contextual, and even semantic and related cognitive factors, are presumably mediated through undivided deep components of cognition. I have described the structure of the conscious system in the divided brain as being Y-shaped, i.e., divided in its upper, more structured levels but undivided below [31]. Each of the separated hemispheric limbs of the "Y," it should be remembered, contains within itself extensive bilateral representation. Each hemisphere, for example, functions with much the usual sense of awareness of the positions and movements of all body parts on both sides, a sense of being able to initiate and direct motor commands for the whole body, and an awareness also of the environment on all sides. Visceral sensations and central states like those involved in hunger, fatigue, etc., also are bilateralized. Even where the ipsilateral representations are weak or absent, there is good reason to think that there is not direct awareness of the ipsilateral deficits. This accords with a general rule that in many respects brains tend to be oblivious of what they lack.

The brain process responsible for a unified conscious experience need not itself be unified, single, or localized. In addition to the recognized diversity

and discontinuity or "graininess" of its neuronal firing patterns, the brain process also is subject to major subdivisions like the left-right and front-back fractionations and the vertical divisions into higher cognitive and deeper emotional components already described. The brain process as such seems to have no counterpart to match the unity, continuity, quality, constancy, and other psychological properties that are experienced subjectively. A hypothesized correlation between mental and neural events based on isomorphic electric fields was suggested by gestalt theory in the 1940s, but was largely abandoned when we found that the insertion of short-circuiting wires or current-distorting dielectric plates all through the visual cortex failed to correspondingly disrupt visual form perception [23,30].

Some years ago we proposed that the answer must lie alternatively in thinking of conscious experience as a functional or operational derivative of the brain process rather than as a spatiotemporal copy or transform [22]. In other words, what counts for subjective unity may lie in the way the brain process functions as a unity or entity regardless of the multilevel and multicomponent make-up of the neural events involved. The overall, holistic functional effect could thus determine the conscious experience. If the functional impact of the neural activity has a unitary effect in the upper-level conscious dynamics, the subjective experience is unified. In these terms the qualities of subjective experience need not correlate with the diverse particulate components of the neuronal infrastructure, only with the function of the active process as a whole. By these operational criteria for generation of subjective meaning the mind may be seen to be largely divided after commissurotomy but unified in the normal intact brain.

VI

Another thing to come out of these concerns for the unity and/or duality of mind, with and without the commissures, is a modified concept of the nature of consciousness. A revised view of the conscious self is involved that includes a formula for mind-brain interaction. For many decades science was traditionally careful to exclude explicitly from its objective explanations any use of conscious or mental forces or phenomena as causal constructs. Mind or subjective experience was accordingly treated in science as an acausal epiphenomenon or as a passive parallel correlate of brain activity, a semantic artifact or most commonly as an inner aspect of the one main physical brain process. In these terms the physiological brain process is assumed to be causally complete in itself with no need or any place for the causal intervention or operation of conscious or mental forces.

The more we learned about the neuronal circuitry and electromechanical mechanisms of brain activity, the more incredible it became to think that the course of these physicochemical events could be influenced in any way

by the qualities of conscious experience. As Eccles [6] phrased it in 1964, "We can, in principle, explain all our input-output performance in terms of activity of neuronal circuits; and consequently, consciousness seems to be absolutely unnecessary" and again "... as neurophysiologists we simply have no use for consciousness in our attempt to explain how the nervous system works." This was the kind of reasoning that had prevailed widely for more than half a century and had led to the philosophy of scientific materialism with its firm renunciation of consciousness and mentalism in science. Behaviorist psychology, with its rigorous rejection of anything mental or subjective, also relied heavily on this reasoning in neuroscience to overcome the otherwise strong subjectivist pressures in cognitive and humanistic psychology and phenomenological thinking as well as in clinical psychology, the field of perception and other subdisciplines where the contents of introspection were indispensible.

Since the mid-1960s our thinking on these matters has undergone some revolutionary changes. In the course of wrestling with the problem of conscious unity in the presence and absence of the cerebral commissures, I became convinced that consciousness is better conceived as being causal in brain activity rather than noncausal and that science had been wrong in denying this for more than half a century [25]. The classical neuronal reasoning of Eccles was perceived to have a flaw or shortcoming. It correctly emphasized the control exerted by neuronal events in determining subjective experience but had been in error in its predication that the course of these physicochemical events could not be influenced by conscious experience. It had failed to recognize the important "downward control" exerted reciprocally by the resultant mental processes on the course of their component neuronal activities. Thus in direct reversal of earlier thinking, my new logic said that neuronal events in the brain, i.e., when, where, and how neurons fire, are determined not only by physicochemical activity but predominantly by the higher laws and dynamics of mental programming.

In these terms we do not look for conscious awareness in the nerve cells of the brain or in the molecules or atoms of brain processing. Along with the larger as well as lesser building blocks of brain function, these elements are common as well to unconscious, automatic, and reflex activity. For the subjective qualities we look higher in the system at organizational properties that are select and special to operations at top levels of the brain hierarchy and that are seen to supersede in brain causation the powers of their neuronal, molecular, atomic, and subatomic infrastructure. The subsidiary components embodied in the conscious processes, such as the timing of neuronal firing and flow patterns of impulse traffic, as well as the inner molecular and atomic "forces within forces" are all carried along in space and time subject to the overriding higher-level dynamics of the mental programming—just as the flow of electrons in a TV receiver is differentially determined by the program content on different channels.

Without going into further detail, we can see that it follows on this revised scheme that mind does actually move matter within the brain [25], and outside as well, indirectly through physical behavior. Further, it now becomes "mind over matter" in a very real sense. This is all within the brain hierarchy, of course. There is no implication that mind is separate from matter in the dualistic sense. Mentalism is no longer equivalent to dualism in the framework of today's modified paradigm. The revolution of the past decade toward increased scientific acceptance of consciousness does not do anything directly to bolster dualist beliefs in the mystical, the paranormal, or supernatural. At the same time, the new position directly opposes prior materialist doctrine that has been telling us for more than half a century that "Man is nothing but a material object, having none but physical properties" and that "Science can give a complete account of man in purely physiochemical terms." These quotes are from the late 1960s by Armstrong [1], a founding father and leader of the materialist, so-called mind-brain identity theory, which still finds support today, though with major reinterpretations to bring it now into close concordance with the causal emergent views of mind outlined above.

Once science thus modifies its traditional materialist-behaviorist stance and begins to accept in theory, and to encompass in principle, within its causal domain the whole world of inner, conscious, subjective experience (the world of the humanities), then the very nature of science itself is changed. The change is not in the basic methodology or procedures, of course, but in the scope of science and in its limitations, in its relation to the humanities and to values and in its role as a cultural, intellectual, and moral force. The kinds of interpretations that science supports, the world picture and attendant value perspectives and priorities, and the concepts of physical reality that derive from science all undergo substantial revisions on these new terms. We come out with a vastly transformed scientific view of ourselves and the world and of the kinds of forces that are in control. The change is away from the mechanistic, deterministic, and reductionistic doctrines of pre-1965 science to the more humanistic interpretations of the 1970s. Our current views are more mentalistic, holistic, and subjectivist. They give more freedom in that they reduce the restrictions of mechanistic determinism and they are more quality rich and more rich in value and meaning.

The pervasive broad paradigm changes involved are particularly welcomed by all who look to science, not alone for objective knowledge and material advances, but also for worldview perspectives and criteria of ultimate value and meaning; those who see science as the best source of true understanding and the most valid route to an intimate comprehension of "the forces that made and move the universe and created Man." Our new mind-brain paradigm qualifies science to assume a higher and more critical societal role that, hopefully, future science will come increasingly to fulfill.

ACKNOWLEDGMENTS

Work of the author and his laboratory have been supported by the National Institute of Mental Health NIMH grant MH3372 and by the F.P. Hixon Fund of the California Institute of Technology.

REFERENCES

1. Armstrong DM (1968): "A Materialist Theory of the Mind." London: Routledge and Kegan Paul.
2. Bogen JE (1969): The other side of the brain. II. An appositional mind. Bull Los Angeles Neurol Soc 34:135–162.
3. Bremer F, Brihaye J, Andre-Baliseaux G (1956): Physiologie et pathologie du corps calleux. Schweiz Archs Neurol Psychiatry 78:31–87.
4. Dennis M, Kohn B (1975): Comprehension of syntax in infantile hemiplegics after hemidecortication: Left hemisphere superiority. Brain Lang 2:472.
5. Dewitt L (1975): Consciousness, mind and self. Br J Philos Sci 26:41–47.
6. Eccles JC (1966): Conscious experience and memory. In Eccles JC (ed) "Brain and Conscious Experience."
7. Ellenberg L, Sperry RW (1980): Lateralized division of attention in the commissurotomized and intact brain. Neuropsychologia 18:411–418.
8. Franco L, Sperry RW (1977): Hemispheric lateralization for cognitive processing of geometry. Neuropsychologia 15:107–114.
9. Gallup GG (1977): Self-recognition in primates. Am Psychol 32:329–338.
10. Gazzaniga MS, Sperry RW (1967): Language after section of the cerebral commissures. Brain 90:131–148.
11. Levy J (1969): Information processing and higher psychological functions in the disconnected hemispheres of human commissurotomy patients. PhD thesis, California Institute of Technology.
12. Levy J (1974): Psychobiological implications of bilateral asymmetry. In Dimond S, Beaumont JB (eds): "Hemisphere Function in the Human Brain." London: Paul Elek, pp 121–183.
13. Levy J (1976): Cerebral lateralization and spatial ability. Behav Genet 6:171–188.
14. Levy J, Nagalaki T (1972): A model for the genetics of handedness. Genetics 72:117–128.
15. Morgan CL (1923): "Emergent Evolution." New York: Holt.
16. Myers RE (1962): Transmission of visual information within and between the hemispheres. In Mountcastle VB (ed): "Interhemispheric Relations and Cerebral Dominance." Baltimore: John Hopkins Press.
17. Nagel T (1971): Brain bisection and unity of consciousness. Synthese 22:396–413.
18. Neisser U (1966): "Cognitive Psychology." New York: Appleton-Century-Crofts.
19. Popper K, Eccles JC (1977): "The Self and Its Brain." New York: Springer International.
20. Puccetti R (1973): Brain bisection and personal identity. Br J Phil Sci 24:339–355.
21. Smith A (1966): Speech and other functions after left (dominant) hemispherectomy. J Neurol Neurosurg Psychiatry 29:467–471.
22. Sperry RW (1952): Neurology and the mind-brain problem. Am Sci 40:291–312.

23. Sperry RW (1957): Brain mechanisms in behavior. Eng Sci 20:24–29.
24. Sperry RW (1961): Cerebral organization and behavior. Science 133:1749–1757.
25. Sperry RW (1965): Mind, brain and humanist values. In Platt JR (ed): "New Views of the Nature of Man." Chicago: University of Chicago Press, pp 71–92.
26. Sperry RW (1968): Mental unity following surgical disconnection of the cerebral hemispheres. Harvey Lect 62:293–323.
27. Sperry RW (1973): Lateral specialization of cerebral function in the surgically separated hemispheres. In McGuigan FJ, Schoonover RA (eds): "The Psychophysiology of Thinking." New York: Academic Press, pp 209–229.
28. Sperry RW (1974): Lateral specialization in the surgically separated hemispheres. In Schmitt FO, Worden FG (eds): "The Neurosciences: Third Study Program." Cambridge: MIT Press, pp 5–19.
29. Sperry RW (1974): Messages from the laboratory. Eng Sci 37:29–32.
30. Sperry RW (1975): In search of psyche. In Worden FG, Swazey JP, Adelman G (eds): "The Neurosciences: Paths of Discovery." Cambridge: MIT Press, pp 425–434.
31. Sperry RW (1976): Mental phenomena as causal determinants in brain function. In Globus G, Maxwell G, Savodnik I (eds): "Consciousness and the Brain." pp 163–177. (Reprinted in Process Studies 5:247–256, 1976.)
32. Sperry RW, Gazzaniga MS (1967): Language following surgical disconnection of the hemispheres. In Milikan CH and Darley FL (eds): "Brain Mechanisms Underlying Speech and Language." New York: Grune & Stratton, pp 108–116.
33. Sperry RW, Gazzaniga MS, Bogen JE (1969): Interhemispheric relationships: the neocortical commissures. Syndromes of hemisphere disconnection. In Vinken PJ, Bruyn GW (eds): "Handbook of Clinical Neurology." Amsterdam: North Holland, pp 273–290.
34. Sperry RW, Zaidel E, Zaidel D (1979): Self-recognition and social awareness in the deconnected hemisphere. Neuropsychologia 17:153–166.
35. Trevarthen CB (1962): Double visual learning in split brain monkeys. Science 136:258–259.
36. Wada JA, Clarke R, Hamm A (1975): Cerebral hemispheric asymmetry in humans. Cortical speech zones in 100 adult and 100 infant brains. Arch Neurol 32:239–246.
37. Zaidel E (1975): A technique for presenting lateralized visual input with prolonged exposure. Vision Res 15:283–289.
38. Zaidel E (1976): Auditory vocabulary of the right hemisphere following brain bisection or hemidecortication. Cortex 12:191–211.
39. Zangwill OL (1974) Consciousness and the cerebral hemispheres. In Dimond S, Beaumont J (eds): "Hemisphere Function in the Human Brain." London: Paul Elek, pp 264–278.